Testimony
on
Analysis of Risk Assessment
Used by the EPA in Support
of Its Proposed Ozone Standards

before the Joint Hearing
of the
Health and Environment Subcommittee
and the
Oversight and Investigations Subcommittee
Commerce Committee
U.S. House of Representatives

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Executive Summary

The approach used by the EPA to assess ozone risks for purposes of standard setting is conceptually sound. For example, the appropriate health endpoints in the sensitive populations and the variation in population response were evaluated. However, several assumptions regarding risk and exposure, result in overestimates of potential health impacts, by several-fold, associated with the proposed ozone standards. This results in overstating the benefits of the proposed standards.

Some assumptions that result in overestimates of health impacts include:

The selective use of "chamber studies" in which exercising individuals are exposed to defined levels of ozone for 6.6 hours. The studies used had the highest response level to ozone. Had other studies been used, the risks would be lower.

Failure to consider adaptation to ozone. People become less responsive to ozone with subsequent exposures. Thus risks are likely to be overstated in cities, such as Los Angeles, where the ozone levels are high enough during summer to induce adaptation.

Overestimates of inhalation rates. The calculation of how much ozone individuals inhale during exercise is overestimated for several reasons, such as the failure to consider the impact of different exercise patterns. If inhalation rates are too high, the fraction of people with potential impacts from ozone will be too high.

Overestimates of modeled ozone concentrations. Recent studies by the American Petroleum Institute (API), using personal ozone monitors, demonstrate that the personal ozone exposures predicted by EPA from fixed monitors are too high.

EPA evaluated hospital admissions for asthma associated with ozone exposure. This analysis is not appropriate to use for decision-making. Hospital admissions could be due to pollutants whose concentrations typically increase when ozone concentrations increase. In addition, the total number of admissions for asthma, even if due to ozone, represents a very small fraction (about 1% or less) of total asthma admissions.

There is much uncertainty in the calculated risks in the different proposed ozone standards. For example, predicted risks for these different standards overlap significantly. Thus, it cannot be said that one standard provides significant improvements over another standard.

Some recommendations for improvement include the following: use of the API studies to modify the exposure estimates; developing an exposure-response relationship using data from studies other than those which yielded the highest response rates; and characterizing the potential impact of adaptation on attenuating the response to ozone in cities such as Los Angeles. (Additional recommendations are in Attachment B.)

In summary, although the approach used by EPA in support of its recommended ozone standards is conceptually sound, multiple biases in the analysis result in an overall overestimate of the risks and, hence, an overestimate of the potential benefits. The uncertainties in the risk assessment preclude conclusions regarding the benefits of one proposed standard over another

The overall approach that EPA takes when evaluating risks for pollutants under as the National Ambient Air Quality Standards (NAAQS) is:

To identify the population of individuals most susceptible to the particular chemical.

To determine the critical health endpoint(s). The health endpoint must be an adverse health effect, rather than a biological response, which may indicate exposure, but not be medically significant.

To evaluate the response of the population of interest under different proposed standards for the particular chemical.

2 Conceptual Approach Used by EPA in Evaluating Proposed Ozone Standards

In developing the proposed ozone standards, EPA considered several endpoints. In particular, EPA focused upon respiratory symptoms, such as pain upon deep inspiration and coughing, and changes in lung function, such as how much air a person could forcibly exhale in one second. These endpoints were selected based on "chamber" studies. In chamber studies, people are exposed to different levels of ozone and changes in their respiratory symptoms and lung function are measured.

To evaluate the proposed ozone standards, responses were predicted in individuals exposed to ozone for different time periods under different conditions of exercise. Specifically, EPA predicted potential impacts in individuals who might exercise heavily for one hour or moderately for eight hours. Consideration of the eight-hour exposure is relevant since some responses occur at lower ozone concentrations when individuals are exposed for longer periods of time (*i.e.*, eight hours *vs.* one hour).

EPA focused on two exposed populations: children exercising outside and adults working outside (*e.g.*, landscapers). Since they are outside, these individuals are more exposed to ozone than the general population. Also, because of their higher activity level, they inhale more ozone.

EPA also considered qualitatively studies in camps in which children were exercising freely and exposed to air pollutants including ozone. These studies were used as general support for the exposure-response relationship derived from the chamber studies. EPA also evaluated the association between hospital admissions for asthma and ozone levels.

The number of individuals in the different exposure duration/exercise level categories who might experience health impacts under different proposed ozone standards was estimated. To evaluate the number of individuals affected, EPA used diary studies in which individuals recorded their activity patterns over several days. By relating activity patterns with time outside and breathing rates, EPA predicted the number of individuals who might be exposed under the different proposed ozone standards.

The number of individuals affected were estimated under different proposed ozone standards. The standards varied based on ozone concentration, averaging time and number of permitted annual exceedances. The standards considered were:

Ozone Concentration	Averaging Time	# of Annual Exceedances
0.10 ppm	1 hr	1
0.12 ppm	1 hr	1
0.07 ppm	8 hr	1
0.08 ppm	8 hr	1
0.08 ppm	8 hr	5
0.09 ppm	8 hr	1
0.09 ppm	8 hr	5
0.10 ppm	8 hr	1

The impact of the proposed standards was compared to the impact of current (*i.e.*, 1990-1991) ozone levels.

We evaluated several elements of EPA's ozone risk assessment:

The relationship between exposure and response to ozone

The estimation of exposure to ozone under present conditions and under future proposed standards

The protectiveness of the different standards, considering in particular uncertainties in the affects occurring under different standards

3 Exposure-Response Relationship

EPA appropriately focused on lung function changes in children exercising outdoors. However, EPA also assumed children would exhibit the same types of respiratory symptoms upon ozone exposure as the adults in the chamber studies. This assumption overestimates risks, since children do not show the same degree of symptoms as adults upon ozone exposure.

Several aspects of EPA's assumptions used to quantify the relationship between ozone exposure and response result in an overestimate of the risks:

For the eight-hour exposure-response relationship, EPA used the results of chamber studies conducted at EPA's laboratory in North Carolina. These individuals showed an increased response to ozone, as compared to individuals exposed in chamber studies in other cities such as Los Angeles. The reason for the differential response is not established. However, the chambers in these studies were contaminated with volatile organic compounds which may have exacerbated the response of the exposed individuals.

The role of adaptation was not considered. Individuals adapt to ozone exposure. That is, their responses become diminished over time with continuing exposure. EPA did not consider adaptation in developing exposure-response relationships for individuals residing in cities such as Los Angeles. The use of an exposure-response relationship from North Carolina will overpredict the response of adapted individuals in other cities.

None of the chamber studies evaluated ozone exposures less than 0.08 ppm. However, EPA has extrapolated below this concentration to evaluate the exposure-response relationship. Such an approach yields significant uncertainties. Because much of the predicted risk is a result of exposures to ozone concentrations of less than 0.08 ppm, the risk estimates are highly uncertain.

The use of the hospital admission studies to predict health impact (*i.e.*, excess hospital admissions) under different ozone scenarios is problematical. Other compounds, such as sulfates and particulate matter, as well as other factors, might affect hospital

admissions for asthma. Thus, it is very difficult to infer any causality between asthma and exposure to ozone from these studies. As an example, consider the observation that the relationship between ozone exposure and hospital admissions for asthma were of greater magnitude in New York City than in White Plains, NY, despite the fact that the ozone concentrations were very similar in both cities. Even if there is a causal relationship between hospital admissions and ozone, the fraction of hospital admissions for asthma attributable to ozone exposure is a very small percent (about 1% or less) of the total admissions for asthma.

4 Exposure

EPA used a multi-faceted model to predict the exposure to individuals under different ozone standards. The net impact of the modeling was to overestimate predicted ozone exposure. This assertion is supported by recent studies in which ozone exposures were actually measured in individuals using personal monitors. Key issues include the following:

EVR, or equivalent ventilation rate, was used to normalize the ventilation rate among individuals with different body sizes. To extrapolate from the chamber studies, EPA used information on the relationship between heart rate and ventilation rate, normalized to EVR, to estimate how much ozone people might take into their bodies under different ozone scenarios. As part of this analysis, EPA used diary studies in which individuals kept diaries of their activity patterns at. By estimating the heart rates of individuals under these different activity patterns, EPA predicted how much ozone people would take into their bodies in different activities. However, there are several uncertainties in this relationship between heart rate and EVR. For example, the relationship was determined with people using leg-only exercise. However, recent studies with individuals using both leg and arm exercise indicate a different relationship. Thus relationship between heart rate and EVR will overestimate how much ozone people take into their bodies under more typical conditions of exercise. In addition, the impact of stress or discomfort on heart rate was not considered in determining the relationship between heart rate and EVR.

The maximum ventilation rate that was assumed by EPA is higher than what would typically occur in most of the population of interest. Very few people could maintain the maximum EVR volume.

The procedures used to predict the future ozone concentrations, namely the rollback procedure, appear to result in a bias several-fold, overpredicting future ozone concentrations under the different standards.

Recent measurements using personal ozone monitors in individuals with different activity patterns indicate that the ozone concentrations, predicted from fixed monitors, are too high, by a factor of about two.

Recent analyses also indicate that there is a negative correlation between vigorous exercise and higher ozone levels (*i.e.*, the higher ozone levels are, the less people exercise vigorously or, the lower the ozone levels, the more people exercise vigorously). Thus much of the calculated risk is based on individuals exercising heavily at low ozone concentrations - concentrations where there are no data and hence much uncertainty about the nature of the exposure-response relationship.

5 Comparison of the Different Standards

The eight hour standard has more biological support than the one-hour standard. However, the same degree of protection can be obtained by a one-hour or an eight hour-standard. For example, the one-hour standard of 0.12 ppm is virtually equivalent to the 0.09-ppm standard for eight hours in terms of percent of individuals affected.

There are relatively small to moderate differences when one compares the impact of five exceedances *versus* one exceedance per year for the eight-hour averaging time. This is because much of the response and risk is a function of ozone concentrations at levels less than the standard. The five exceedances is a more appropriate method for evaluating compliance with the standard in that it would be more robust and result in less "flip-flop" - that is a region going in and out of the attainment on a year-to-year basis.

As noted earlier, there are significant uncertainties in the models that EPA used to predict the future risk. Another source of uncertainty is the modeling procedure itself. Specifically, running the model for a single scenario will yield different results for different model runs. This makes it very difficult to distinguish between the health protectiveness of the different standards. Thus one cannot readily demonstrate that lower standards provide much more public health benefit than the higher standards.

6 Recommendations

The scientific foundation of the ozone risk assessment could be improved in several way. These include the following:

Exposure-response relationships should be developed using results from the studies in addition to those in North Carolina. The issue of the contamination of the chambers in North Carolina needs to be resolved.

The role of adaptation in affecting the responses to ozone in cities such as Los Angeles needs to be better characterized and quantified as part of the exposure-response relationship.

The estimation of EVR under different heart rate conditions needs to be better quantified considering recent published studies in which heart rate is correlated with ventilation rate.

The estimating of future ozone levels using the Rollback procedure needs to be corrected.

The results of recent validation studies in which actual ozone exposures were measured in volunteers needs to be incorporated into the exposure model so that the predicted exposures are more accurate.

Also, the uncertainties in the risk assessment and their impact on ability to distinguish between the different studies must be better articulated. Additional recommendations are provided in Attachment B.

7 Conclusions

In summary, although the approach used by EPA in support of its recommended ozone standards is conceptually sound, multiple biases in the analysis result in an overall overestimate of the risks and, hence, an overestimate of the potential benefits. The uncertainties in the risk assessment preclude conclusions regarding the benefits of one proposed standard over another.

Attachments: A. Dr. Beck's Resume

B. Executive Summary & Conclusions/Recommendations Chapter from Gradient Report *Analysis of Exposure Response Assessment Used in Support of the Environmental Protection Agency's Proposed Ozone Standards*

Attachment A Dr. Beck's Resume

BARBARA D. BECK
Principal

AREAS OF EXPERTISE

Risk assessment, exposure assessment, toxicology, metals, inhaled pollutants, soil contaminants, technical support for litigation.

EDUCATION AND CERTIFICATIONS

Ph.D., Molecular Biology and Microbiology, Tufts University, 1975.

A.B., Biology, Bryn Mawr College, 1968.

Mid-America Course in Toxicology, 1988.

Diplomat, American Board of Toxicology, 1988; recertified, 1993.

PROFESSIONAL EXPERIENCE

1987 - Present GRADIENT CORPORATION, Cambridge, MA

Principal. Environmental consulting practice includes evaluation of chemical toxicity, health risk assessment for cancer and non-cancer endpoints, review of animal toxicology studies, and multi-media assessment of exposure to environmental chemicals. Special emphasis on metals and inhaled chemicals.

1985 - Present HARVARD SCHOOL OF PUBLIC HEALTH, Boston, MA

Visiting Lecturer in Toxicology.

1985 - 1987 REGION I ENVIRONMENTAL PROTECTION AGENCY, Boston, MA

Regional Expert in Toxicology and Supervisory Scientist, Air Toxics Staff. Performed risk assessments for toxic air pollutants. General staff responsibilities included air impacts at waste sites, state air toxic programs, and EPA radiation programs.

1979 - 1985 HARVARD SCHOOL OF PUBLIC HEALTH, Cambridge, MA

Research Associate in Environmental Science and Physiology and Fellow in Interdisciplinary Programs in Health. Developed short-term animal bioassay for pulmonary toxicants. Editor and author of monograph on variations in susceptibility to inhaled pollutants for both cancer and non-cancer endpoints.

1978 - 1979 TUFTS UNIVERSITY SCHOOL OF MEDICINE, Boston, MA

Instructor in Protein Chemistry. Isolated phagocytosis inhibiting factor from immunoglobulin of individuals with inherited susceptibility to bacterial infections.

1977 - 1978 HARVARD UNIVERSITY, Cambridge, MA

Postdoctoral Fellow in Biology. Researched novel properties of bacterial protein elongation factor, EF-Tu, relevant to possible role as a structural protein.

1975 - 1976 UNIVERSITY OF MASSACHUSETTS MEDICAL SCHOOL, Worcester, MA

Postdoctoral Fellow in Microbiology. Isolated and analyzed messenger RNA from slime molds. Initiated project on elongation factor, EF-Tu.

1968 - 1969 TUFTS UNIVERSITY SCHOOL OF MEDICINE, Boston, MA

Research Assistant in Molecular Biology and Microbiology. Performed genetic and biochemical studies on bacterial lipopolysaccharide.

ACTIVITIES

- Membership Committee, Society of Toxicology, 1997 to present.
- Continuing Education Committee, Society of Toxicology, 1996 - 1997.
- Risk Assessment Task Force, Society of Toxicology, 1996 to present.
- Advisory Committee to Public Health Program, Florida A & M University.
- Chair of Session on Ecological and Human Health Protocols at GRI meeting on Environmentally Acceptable Endpoints in Soil, Arlington, VA, 1995.
- Session Chair, International Conference on Arsenic, San Diego, CA, 1995.
- Watertown, MA, Board of Health, 1995 - present.
- Rapporteur 1994. USEPA Meeting on Risk Assessment for Chemical Mixtures, Research Triangle Park, NC.
- Program Committee, Society of Toxicology, 1993 - 1996.
- Member of Arsenic Task Force, Society for Environmental Geochemistry and Health, 1993 - present.
- Work group on arsenic, Society for Environmental Geochemistry and Health, 1993.
- President, Society of Toxicology, Risk Assessment Specialty Section, 1994 - 1995.
- Vice President, Society of Toxicology, Risk Assessment Specialty Section, 1993 - 1994.
- President, Northeast Chapter of the Society of Toxicology, 1992 - 1993.
- Review committee, EPA Workshop on the Methodology for Deriving National Ambient Water Quality Criteria for the Protection of Human Health, 1992.
- Consultant to SAB Committee on Hazardous Air Pollutants, 1991.

- Member of Advisory Committee to EPA on Metal Bioavailability, 1990.
- Member of Advisory Committee to Harvard Center for Risk Analysis, 1990 - 1993.
- Member of Committee on Public Communications, Society of Toxicology, 1990 - 1992.
- Councilor of Inhalation Specialty Section, Society of Toxicology, 1990 - 1992.
- Member of Technical Committee of Council for Health and Environmental Safety of Soils (CHESS), 1988 - Present.
- President, Northeast Chapter of the Society for Risk Analysis, 1987 - 1988.
- EPA Risk Assessment Forum, 1986 - 1987.
- Maine Science Advisory Panel, 1986 - 1990.
- Air Toxics Committee of Northeast States for Coordinated Air Use Management, 1985 - 1987.
- Rhode Island Air Toxics Advisory Committee, 1986 - 1987.
- Massachusetts Visibility/Public Health Index Peer Review Team, 1986.
- Massachusetts Air Toxics Guidelines Review Committee, 1985 - 1988.
- Peer Review Committee, EPA Inhalation RfD Document, 1987.

PROFESSIONAL ASSOCIATIONS

American Thoracic Society • Society of Toxicology • Northeast Chapter of the Society of Toxicology • Society for Risk Analysis • New England Chapter of the Society for Risk Analysis • American Association for the Advancement of Science • Society of Environmental Geochemistry and Health • International Society for Exposure Assessment

PROJECT LIST

Chemical Manufacturers Association: Review of EPA land disposal regulations Phase IV. Review of ozone risk assessment in EPA ozone staff paper.

American Petroleum Institute: Role of risk assessment and potential cost savings in Superfund remedy selection process.

Midwestern Utility: Assessment of health risks associated with manufactured gas plant sites. Preparation of risk assessment manual for typical compounds at these sites.

People's Gas Light & Coke Company; New Jersey Natural Gas; South Jersey Gas Company; Indiana Gas: Expert witness testimony regarding the historic understanding of the toxicity of chemicals associated with manufactured gas plant sites for four separate rate setting cases.

Zinc Corporation of America: Risk assessment using both environmental and epidemiological data for lead and cadmium in soil at a Superfund site.

Major Canadian Mining Company: Evaluation of arsenic exposure at mining/milling site using biological monitoring, risk assessment for arsenic, and communication with the public and regulatory agencies.

Coors: Review of dichloroethane toxicology and estimation of permissible level for water exposure.

National Mining Association: Review of EPA supplemental land disposal regulations Phase IV.

Major Mining Company: Review of historical toxicological knowledge of lead.

Law Firms Representing Multiple PRPs: Evaluation of historical uses, and standards and criteria for trichloroethylene.

American Cyanamid: Development of risk screening process for evaluating potential hazards at international sites as part of property transfer.

PRP Group at Smelter Site: Analysis of impact of soil removal activities on lead levels in soil and dust.

EPA, Office of Research and Development: Development of toxicity data base for inhalation exposure to the Hazardous Air Pollutants listed under the 1990 Clean Air Act Amendments.

Elf Atochem: Presentation on uncertainties in arsenic toxicology and risk assessment.

Cabot Corporation: Development of health-based sediment removal levels at Superfund site involving multiple industrial sources.

Major Consumer Product Manufacturer: Development and application of adult blood lead model to predict blood lead levels from discontinuous exposures to lead released from a consumer product.

Al-Tech: Development of risk-based exclusion limit for metals in slag.

Conestoga - Rovers & Associates: Evaluation of methodologies and assumptions used by EPA and other investigators to estimate risks from polychlorinated biphenyls in soils and sediments, with particular emphasis on dermal absorption.

Buckman Chemical Company: Review of toxicity of barium compounds in cost allocation project.

ASARCO: Monte Carlo air modeling and risk assessment at operating smelter.

Lead Industries Association: Critique of HUD cost benefit analysis on apartment deleading.

Frilot, Partridge, Kohnke & Clements: Lead risk assessment for hunting and construction scenarios in recreational area.

Southern Utility: Evaluation of potential health studies at former MGP site.

Western Utility: Evaluation of historic understanding of toxicity of chemicals associated with manufactured gas plant sites.

Gardere and Wynne: Evaluation of potential public health impacts of benzene.

Canadian Mining Company: Evaluation of exposure to arsenic in tailings.

U.S. Silica: Evaluation of arsenic exposure in industrial setting.

Major Automobile Manufacturer: Risk assessment at battery manufacturing facility; assistance in development of sampling plan.

ELI: Risk assessment for lead, asbestos, PCBs and other chemicals in soil and water at former brake lining manufacturing facility.

Nugent, Fitzgerald, McGroarty & McFadden: Evaluation of potential risks from VOCs in groundwater.

Battery Manufacturing Company: Development and oversight on sample collection and analysis program for lead exposure, evaluation of existing blood lead and tooth lead data and application of blood lead model as part of toxic torts case. Provided oral deposition testimony.

ARCO/Denver: Risk assessment support for several major mining-related Superfund sites in the western U.S. Evaluation of toxicology, epidemiology, and bioavailability of metals, including lead and arsenic.

Cyprus/Amax: Human health risk assessment for arsenic, lead, cadmium, and other metals in soil at mining and milling sites. Review of other risk assessments.

International Lead Zinc Research and Organization: Development of probabilistic blood lead model.

Confidential Chemical Manufacturer: Risk assessment for tin compounds.

Anitec: Development of work plan for risk assessment and subsequent risk assessment at film manufacturing site.

Marine Shale Processors: Risk assessment of lead, other inorganics and organic compounds in aggregate produced by hazardous waste recycling. Evaluation of risks of air emissions during incineration process. Provided expert testimony.

Green Mountain Power: Critique of EPA risk assessment at former manufactured gas plant site.

Atlanta Gas & Light; Washington Natural Gas; South Jersey Gas: Expert witness support regarding historical knowledge of toxicology, chemistry, and regulations of chemicals associated with manufactured gas plants in insurance cases involving cost recovery.

Confidential Canadian Utility: Non-testifying expert support in civil case regarding historical knowledge of toxicology, chemistry and regulations of chemicals associated with manufactured gas plants.

Remedial Trust representing Consortium of PRPs: Evaluation of research plan involving groundwater modeling and remedial approaches at former manufacturing site. Evaluation of biomonitoring approaches for metals.

Coalition for Clean Air Act Implementation: Evaluation of technical issues, including use of composite scores, in 112(g), trading of hazardous air pollutants. Quantification of uncertainty in the composite source.

Taft, Stettinius, and Hollister: Evaluation of risk assessment approach under RCRA at former pesticide manufacturing site, presently used for other manufacturing processes.

Golden and Mandel: Review of toxicology of atmospheric sulfuric acid.

Canadian Mining Company: Arsenic risk assessment at tailings site. Risk assessment for multiple metals associated with tailings release at mine in Southeast Asia.

Cement Kiln/Recycled Steel Manufacturer: Risk assessment support for ongoing operations.

Giant Cement: Risk assessment support litigation involving ongoing operations.

Howrey and Simon: Historical review of toxicology of MGP chemicals for Midwestern Utility Co.

Major U.S. Brewery: Risk assessment for adult workers exposed to lead from paint in soil.

Gorman, Waszkiewicz: Litigation support case involving alleged exposure to municipal landfill chemicals.

Horsehead Industries: Evaluation of multipathway risks associated with slag use. Critique of EPA Hazardous Waste Identification Rule.

Confidential Utility Client in Eastern U.S.: Non-testifying expert support in civil case regarding historical knowledge of toxicology, chemistry and regulations of chemicals associated with manufactured gas plants.

ARCO/Los Angeles: Preparation of technical comments on toxicological evaluation and risk assessment used for listing of lead by Cal EPA as toxic air pollutant.

Confidential Canadian Refiner/Smelter: Evaluation of proposed remedial action for lead.

Homestake Mining: Evaluation of risks of lead in soil at concentrate transfer station.

Exide: Evaluation of risks of lead in soil at smelter and battery crushing sites.

Health Effects Institute: Assessment of literature on carcinogenicity of inhaled diesel exhaust particulates, especially using urine mutagenicity. Review of literature on toxicity of carbon monoxide and effects on individuals with angina.

Davis, Graham & Stubbs: Evaluation of health risks for metals from a mining/smelting site in the Western US, including review of metal bioavailability and epidemiology studies.

Consortium of Massachusetts Utilities: Review of toxicological knowledge of chemicals at manufactured gas plant sites over time for Massachusetts generic rate setting case.

Chrysler Corporation: Technical review of toxicological and risk assessment assumptions in hazardous waste regulations proposed by a state environmental agency.

Ballard Spahr Andrews & Ingersoll: Critique of agency risk assessment for metals in soil at historic smelter and mining site in Western U.S.

DyKema & Gossett: Evaluation of non-cancer risks from alkylphenols in groundwater at a wood tar site, based on structure activity relationships. Evaluation of risks from polycyclic aromatic hydrocarbons.

Haley & Aldrich: Risk assessment for volatile chemicals possibly entering a building, due to site remediation.

Woodard, Hall, & Primm: Litigation support in toxic tort case involving potential exposure to organic solvents from a chemical refinery site.

Syntex Corporation: Critique of Federal Register notice on delisting of incinerator ash from RCRA regulations. Reviewed applicability of model to dioxin contaminated ash.

U.S. Dept. of Navy: Risk assessment for volatiles released from waste water treatment plant.

Occidental Petroleum: Risk assessment for volatile compounds, polycyclic aromatic hydrocarbons, and metals in air, soil, and water associated with historic refinery operations and with natural gas and petroleum formations.

American Red Cross: Review of toxicity of new blood bag plasticizer and assessment of potential risks to blood product recipients.

American Lung Association of Maine: Technical advice on health effects of criteria and non-criteria air pollutants. Review of regulatory packages.

Northeast Status for Coordinated Air Use Management: Technical assistance in organizing conference on use of bioassays in evaluating ambient air pollutants and presentation of report on use of short-term pulmonary bioassays in evaluation of toxicity and potential health effects of urban particulates.

RJR/Nabisco: General assistance in evaluation of studies on reference and "non-burning" cigarette and in organizing conferences. Critique of OSHA risk assessment for environmental tobacco smoke.

ENSAFE: Risk assessment for metals in soil at U.S. Navy shipyard for RCRA clean closure.

Burns & Levinson/Driscoll, Gillespie, Stanton & Davis: Litigation support for a toxic torts case involving neurotoxicity and exposure to industrial solvents.

N.J. Dept. of Environmental Protection: Site assessment and risk assessment for specialty chemical manufacturing site in N.J. involving volatile organic chemicals and DDT.

EPA/Mathtech: Development of work plan to conduct morbidity or mortality study, using readily available data bases, for high ozone levels experienced in summer of 1988.

Davis, Graham & Stubbs: Risk assessment for arsenic-contaminated soil. Assessed human health risks via inhalation and ingestion and ecological risks to deer populations.

Bridgewater Energy Center: Review of regulations regarding disposal of incinerator ash. Also reviewed air emissions from RDF facilities in comparison with emissions from traditional incinerators.

Massachusetts Attorney General: Expert witness testimony on the use of risk assessment for the siting of an energy facility.

Colorado Dept. of Law: Assessment of toxicological studies on nerve gas degradation product.

Region I EPA: Compilation and review of air toxics monitoring studies in Region I with respect to adequacy in reflecting human exposure and in identifying relevant sources from a risk perspective.

Region II EPA: Evaluation of health sciences issues as part of litigation support at Love Canal for exposure assessment, toxicology, and risk assessment.

Long, Weinberg, Ansley & Wheeler: Review of multi-route exposure to wood treating chemicals and potential health effects for toxic torts case.

Kaye, Scholer, Fierman, Hays & Handler: Inhalation risk assessment for volatile organic compounds at a landfill in the Western US.

General Electric: Toxicity profiles of chemicals used in plastics production.

Chevron Corporation: Ecological and human health risk assessment for solvent extracted soils originally contaminated with petroleum waste, based on potential to contaminate nearby harbor.

Browning Ferris Inc.: Inhalation risk assessment for chemicals released from existing landfill and from proposed expansion.

Parsons, Behle, & Latimer: Litigation support for lead and arsenic-contaminated site in western U.S., including critique of risk assessments and assistance in design and interpretation of epidemiological study.

Budd, Larner, Gross, Rosenbaum, Greenberg & Sade: Risk assessment for soil contaminated with dioxin at a solvents site in St. Louis, MO. Evaluation of acceptable level for dioxin via inhalation and dermal exposure.

Driscoll, Gillespie, Stanton & Davis/Sugarman, Rogers, Barshak & Cohen: Litigation support in toxic tort case involving claim of neurological damage associated with exposure to a contaminant in a consumer product.

Sugarman, Rogers, Barshak & Cohen: Litigation support in case involving benzene exposures.

Keck, Mahin, & Cate: Litigation support for a law suit involving environmental contamination of wood treatment chemicals.

Gas Research Institute: Assist in preparation of exposure manual for MGP sites.

Atlantic Environmental/Gas Research Institute: Development of exposure manual for MGP sites.

PUBLICATIONS

Articles

Brown, K.G. and B.D. Beck. 1996. Arsenic and bladder cancer mortality. *Epidemiol*. 7:557-558.

Slayton, T. M., B. D. Beck, K. A. Reynolds, S. D. Chapnick, P. A. Valberg, L. J. Yost, R. A. Schoof, T. D. Gauthier, and L. Jones. 1996. Issues in Arsenic Cancer Risk Assessment. *Env. Health Perspect*. 104:2-4.

Brain, J. D., J. D. Blanchard, J. Heyder, S. F. Wolfthal, and B. D. Beck. 1996. Relative toxicity of di(2-ethylhexyl) sebacate and related compounds in an *in vivo* hamster bioassay. *Inhal. Toxicology*. 8:579-593.

Shifrin, N.S., B.D. Beck, T.D. Gauthier, S.D. Chapnick, and G. Goodman. 1996. Chemistry, toxicology, and human health risk of cyanide compounds in soils at former manufactured gas plant sites. *Regul. Toxicol. Pharmacol.* 23:106-116.

Rudel, R., T.M. Slayton, and B.D. Beck. 1996. Implications of arsenic genotoxicity for dose-response of carcinogenic effects. *Regul. Toxicol. Pharmacol.* 23:87-105.

Sexton, K., B.D. Beck, E. Bingham, J.D. Brain, D.M. DeMarini, R.C. Hertzberg, E.J. O'Flaherty, and J.G. Pounds. 1995. Chemical mixtures from a public health perspective: the importance of research for informed decision making. *Toxicology*. 105: 429-441.

Beck, B.D., P.D. Boardman, G.C. Hook, R.A. Rudel, T.M. Slayton, R.H. Carlson-Lynch. 1995. Response to Smith *et al. Env. Health Perspect.* 103(1):15-17.

Beck, B.D., R.A. Rudel, G.C. Hook, and T.S. Bowers. 1995. Risk Assessment. In *Organ-Specific Metal Toxicology*. (Klaasen, C., M. Waalkes, and R. Goyer). Academic Press. pp. 144-185.

Beck, B.D., R. Rudel, E.J. Calabrese. 1994. The use of toxicology in the regulatory process. In *Principles and Methods of Toxicology*. (Hayes, A.W., ed.) Raven Press, New York. pp. 19-58.

Carlson-Lynch, H., B.D. Beck, and P.D. Boardman. 1994. Arsenic risk assessment. *Env. Health Pers.* 102(4):354-356.

Bowers, T.S., B.D. Beck, H.S. Karam. 1994. Assessing the relationship between environmental lead concentrations and adult blood lead levels. *Risk Analysis.* 14(2):183-189.

Beck, B.D. 1993. Coauthor of section on antimony in "Metals bioavailability and disposition kinetics - research needs." Workshop (Chairman, J. McKinney). *Toxicol. and Environ. Chem.* 38. pp 1-71.

Beck, B.D., R.B. Conolly, M.L. Dourson, D. Guth, D. Hattis, C. Kimmel, and S.C. Lewis. 1993. Improvements in quantitative noncancer risk assessment. *Fund. Appl. Toxicol*. 20:1-14.

Rudel, R.A. and B.D. Beck. 1993. Risk assessment for indoor air: evaluating risks to susceptible populations. In *Methods of Risk Assessment for Indoor Environment* (Ed. B. Seifert). NATO/CCMS Pilot Study of Indoor Air. Quality and European Collaborative Action. Indoor Air Quality and its Impact on Man (Formerly Cost Project 613). Report on a joint Workshop, held October 15 - 17, 1991 in Kloster Banz, Federal Republic of Germany. pp. 67-80.

Calabrese, E.J., B.D. Beck, and W.R. Chappell. 1992. Does the animal-to-human uncertainty factor incorporate interspecies differences in surface area? *Reg. Toxicol. Pharmacol.* 15: 172-179.

Brainard, J., and B.D. Beck. 1992. A review of the bioavailability of petroleum constituents. *J. Soil Contam.* 1:273-307.

Beck, B.D. 1992. Symposium overview: an update on exposure and effects of lead. *Fund. Appl. Toxicol.* 18:1-16.

Hemphill, C.P., M.V. Ruby, B.D. Beck, A. Davis, and P.D. Bergstrom. 1991. The bioavailability of lead in mining wastes: physical/chemical considerations. *Chemical Speciation and Bioavailability*. 3: 135-148.

Karam, H.S. and B.D. Beck. 1991. Evaluation of two methods for determining cleanup levels for mining derived lead in soil. *Proceedings of the 24th Annual Conference on Trace Substances in Environmental Health and Annual Meeting of the Society for Environmental Geochemistry and Health*. July 9-12, pp. 98-104.

Beck, B.D., A.P. Toole, B.G. Callahan, and S.K. Siddhanti. 1991. Utilization of quantitative structure activity relationships (QSARs) in risk assessment: Alkylphenols. *Reg. Toxicol. Pharmacol*. 14: 273-285.

Petito, C.T. and B.D. Beck. 1991. Evaluation of evidence of non-linearities in the dose-response curve for arsenic carcinogenesis. *Proceedings of the 24th Annual Conference on Trace Substances in Environmental Health and Annual Meeting of the Society for Environmental Geochemistry and Health*, July 9-12, pp. 143-176.

Karam, H.S. and B.D. Beck. 1990. Current issues in determining acceptable levels for lead in soil. *Comments on Toxicology*. 3:509-529.

Steele, M.J., B.D. Beck, B.L. Murphy, and H.S. Strauss. 1990. Assessing the contribution from lead in mining wastes to blood lead. *Reg. Toxicol. Pharmacol*. 11:158-190.

Beck, B.D., E.J. Calabrese, and P.D. Anderson. 1989. The use of toxicology in the regulatory process. In *Principles and Methods of Toxicology*. (Hayes, A.W., ed.) Raven Press, New York. pp. 1-28.

Beck, B.D. 1989. Risk assessment for soils contaminated with petroleum products: An overview. In *Petroleum Contaminated Soils*, Vol. 1 (Kostecki, P.T. and Calabrese, E.J., eds.). pp. 221-224. Lewis Publishing, Chelsea, MI.

Beck, B.D. 1990. Overview on adverse effects of ozone. Preface. In *Ozone Risk Communication and Management* (Calabrese, E.J., Gilbert, C.E. and Beck, B.D., eds.). Lewis Publishing, Chelsea, MI.

Rose, R.M., J.M. Fuglestad, W.A. Skornik, S.M. Hammer, S.F. Wolfthal, B.D. Beck, and J.D. Brain. 1988. The patho-physiology of enhanced susceptibility to murine cytomegalovirus respiratory infection during short-term exposure to 5 ppm nitrogen dioxide. *Am. Rev. Respir. Dis.* 137:912-917.

Weinstock, S. and B.D. Beck. 1988. Age, nutrition, and susceptibility to non-neoplastic lung disease. In *Variations in Susceptibility to Toxic Agents in the Air: Identification, Mechanisms, and Policy Implications* (Brain, J.D., Beck, B.D., Warren, J. and Shaikh, R., eds.). Johns Hopkins Press, Baltimore, MD. pp. 104-126.

Beck, B.D. and S. Weinstock. 1988. Gender and susceptibility to non-neoplastic lung diseases. Ibid. pp. 127-141.

Beck, B.D. and I. Greaves. 1988. Screening and monitoring for non-neoplastic lung diseases. Ibid. pp. 335-375.

Warren, A.J. and B.D. Beck. 1988. Screening and monitoring for exposure and susceptibility to carcinogens. Ibid. pp. 376-418.

Musk, A.W., B.D. Beck, H.W. Greville, J.D. Brain, and D.E. Bohannon. 1988. Pulmonary disease from exposure to an artificial aluminum silicate. *Br. J. Ind. Med.* 45:246-250.

Beck, B.D. 1987. Assessing health risks from chemical contaminants in soil. *Comments on Toxicol.* 7:171-175.

Beck, B.D., H.A. Feldman, J.D. Brain, T.J. Smith, M. Hallock, and B. Gerson. 1987. The pulmonary toxicity of talc and granite as estimated from an *in vivo* hamster bioassay. *Toxicol. Appl. Pharmacol.* 87:222-234.

Beck, B.D., J.D. Brain, and S.F. Wolfthal. 1987. Assessment of lung injury produced by particulate emissions of space heaters burning automotive waste oil. *Ann. Occup. Hyg.*

Hallock, M.F., T.J. Smith, S.K. Hammond, B.D. Beck, and J.D. Brain. 1987. A new technique for collecting ambient diesel particles for bioassays. *Am. Ind. Hyg. Assoc. J.* 48:487-492.

Brain, J.D. and B.D. Beck. 1985. Bioassays for minerals dusts and other particulates. In *In vivo Effects of Minerals Dusts* (Beck, E.G. and Bignon, J., Eds.). NATO ASI Series Vol. G3 pp. 323-335. Springer-Verlag, New York.

Brain, J.D. and B.D. Beck. 1985. Bronchoalveolar lavage. In *The Toxicology of Inhaled Materials. General Principles of Inhalation Toxicology* (Witschi, H.P., and Brain, J.D., Eds.). pp. 203-226. Springer Verlag, New York.

Beck, B.D., B. Gerson, H.A. Feldman, and J.D. Brain. 1983. Lactate dehydrogenase isoenzymes in hamster lung lavage fluid after lung injury. *Toxicol. Appl. Pharmacol.* 71:59-71.

Beck, B.D. and J.D. Brain. 1983. Predicting the pulmonary toxicity of particulates using damage indicators in lung lavage fluid. In *Health Issues Related to Metals and Nonmetallic Mining* (Wagner, W.L., Rom, W.N., and Merchant, J.A., Eds.). pp. 83-104. Butterworth Publishers, Woburn, MA.

Brain, J.D. and B.D. Beck. 1983. Assessment of particulate toxicity. Ibid. pp. 51-61.

Beck, B.D. and J.D. Brain. 1982. Prediction of the pulmonary toxicity of respirable combustion products from residential wood and coal stoves. In *Residential Wood and Coal Combustion*, pp. 264-280. Air Pollution Control Association, Pittsburgh, PA.

Beck, B.D., J.D. Brain, and D.E. Bohannon. 1982. A short term *in vivo* bioassay using hamsters to assess the toxicity of particulates for the lungs. *Toxicol. Appl. Pharmacol.* 66:9-29.

Beck, B.D., J.D. Brain, and D.E. Bohannon. 1981. The pulmonary toxicity of an ash sample from the Mt. St. Helens volcano. *Exp. Lung Res.* 2:289-301.

Smith, T.J., B.D. Beck, J.D. Brain, W.C. Hinds, S.G. Baron, and L. Weil. 1982. Prediction of pneumoconiosis risk by bioassays of particulates from occupational exposures. *Ann. Occup. Hyg.* 26:435-348.

Beck, B.D. 1979. Polymerization of the bacterial elongation factor, Tu. *Eur. J. Biochem.* 97:495-502.

Beck, B.D., P.G. Arscott, and A. Jacobson. 1978. Novel properties of the bacterial elongation factor, EF-Tu. *Proc. Natl. Acad. Sci. USA* 75:1250-1254.

Beck, B.D. and J.T. Park. 1977. Basis for the observed fluctuation of carboxypeptidase II activity in BUG 6, a temperature sensitive mutant of *Escherichia coli* K-12. *J. Bacteriol.* 130:1292-1301.

Beck, B.D. and J.T. Park. 1976. Activity of three murein hydrolases during the cell division cycle of *Escherichia coli* K-12 as measured in toluene-treated cells. *J. Bacteriol.* 126:1250-1260.

Mirelman, D., B.D. Beck, and D.R.D. Shaw. 1974. The location of the D-alanyl ester in the ribitol teichoic acid of *Staphylococcus aureus. Biochem. Biophys. Res. Comm.* 39:712-717.

Abstracts

Cohen, J.T., M.A. Lampson, and B.D. Beck. 1997. Use of a Monte Carlo exposure model to estimate blood lead distributions in U.S. children. *The Toxicologist* 36:337-338.

Cohen, J.T., B.D. Beck, and T.S. Bowers. 1996. Validation of an arsenic model through urine and fecal measurements. *The Toxicologist* 30:49.

Cohen, J.T., B.D. Beck, P.D. Boardman, L.A. Beyer, and D. Hiller. 1995. Use of an arsenic exposure model at a gold mining and milling site. Presented at 1995 International Conference on Arsenic, San Diego, CA.

Beck, B.D., P.D. Boardman, L.A. Beyer, J.T. Cohen, and D. Hiller. 1995. Validation of an arsenic exposure model at a mining and milling site through urinalysis. Presented at 1995 International Conference on Arsenic, San Diego, CA.

Slayton, T.M., B.D. Beck, and P.A. Valberg. 1995. Evaluation of health effects resulting from accidental exposures. Presented at 1995 Air and Waste Management meeting.

Beck, B.D., P.D. Boardman, and A. Watson. 1995. Urinalysis study for evaluating arsenic exposure in a population residing on mill tailings. *The Toxicologist* 15:87.

Beck, B.D., G. Goodman, and T.D. Gauthier. 1994. Risk assessment for cyanides in soil at manufactured gas plant (MGP) sites. *The Toxicologist* 14:154.

Schoof, R.A., L.J. Yost, P.A. Valberg, and B.D. Beck. 1994. Recalculation of the oral arsenic reference dose and cancer slope factor using revised assumptions in inorganic arsenic intake from food. *The Toxicologist* 14:37.

Bowers, T.S., A.R. Michelson, and B.D. Beck. 1994. Short-term lead exposure modeling. *The Toxicologist* 14:36.

Beck, B.D. and T.S. Bowers. 1993. Uptake of Pb into the body: geochemical characteristics affecting uptake, host modifying factors, and approaches to quantify. *Proceedings of the 1993 Annual Meeting of the Geological Society of America*.

Karam, H.S., B.D. Beck, G. Goodman and M.J. Steele. 1993. The value of blood lead measurements in children in estimating past, present, and future exposures to lead: Application to risk management decisions at Superfund sites. *The Toxicologist* 13(1):302.

Beck, B.D., T.S. Bowers and H.S. Karam. 1993. An adult lead risk assessment model. *The Toxicologist* 13:141.

Beck, B.D. and M.L. Dourson. 1992. Improvements in quantitative noncancer risk assessment: Introduction. *The Toxicologist.* 12(1):23.

Beck, B.D. and H.S. Karam. 1990. Evaluation of two methods to determine cleanup levels for lead in soil. *Proceedings of the 24th Annual Conference on Trace Substances in Environmental Health.*

Petito, C.T. and B.D. Beck. 1990. Evaluation of non-linearities in the dose response curve for arsenic carcinogenesis. *Proceedings of the 24th Annual Conference on Trace Substances in Environmental Health.*

Beck, B.D. and J.D. Brain. 1988. Application of short-term lung bioassays to risk assessment for metals. *The Toxicologist.* 8:154.

Beck, B.D. and P.Y. Tsai. 1987. Risk assessment for lead contaminated soil. *The Toxicologist.* 7:729.

Beck, B.D., J.D. Brain, S.F. Wolfthal, J. Zibrak, and S. Sommers-Smith. 1985. Possible sources of biochemical indicators of lung injury in bronchoalveolar lavage fluid from hamsters. *Am. Rev. Respir. Dis.* 131:A184.

Zibrak, J.D., B.D. Beck, J. Sadoski, S. Wolfthal, B. Gerson, and S. Sommers-Smith. 1985. Cytoplasmic enzyme patterns in isolated hamster alveolar type II cells (ATII). *J. Cell. Biol.* 99:(abs).

Beck, B.D., J.D. Brain, and S.F. Wolfthal. 1984. Are combustion products of automobile waste oil (AWO) toxic to the lungs? *Am. Rev. Respir. Dis.* 129:152.

Beck, B.D., J.D. Brain, and N.S. Shera. 1983. Acute indicator of lung damage in hamsters exposed to bleomycin plus 70% O2 or elastase. *Am. Rev. Respir. Dis.* 127:171.

Beck, B.D., B. Gerson, H. Feldman, and J.D. Brain. 1982. LDH isoenzymes in hamster lung lavage fluid as a means of assessing pulmonary damage. *Am. Rev. Respir. Dis.* 125:230.

Beck, B.D., J.D. Brain, and D.E. Bohannon. 1982. Are respirable combustion products from home heating stoves toxic to the lungs? *Am. Rev. Respir. Dis.* 125:156.

Beck, B.D., J.D. Brain, and D.E. Bohannon. 1981. Will Mt. St. Helens volcanic ash injure the lungs? *Am. Rev. Respir. Dis.* 123:149.

Beck, B.D. and J.T. Park. 1974. Study on the relationship between three murein hydrolases and cell division in *E. coli. Annu. Meeting Amer. Soc. Microbiol.* G38:26.

Other Publications/Reports

Valberg, P.A., B.D. Beck. 1993. "Recalculation of the Arsenic Cancer Slope Factor." Submitted to IRIS Information Submission Desk (U.S. EPA) on August 9, 1993.

Beck, B.D., G. Goodman, and C.P. Hemphill. 1993. "Summary of Naphthalene Toxicity Information and Derivation of a Naphthalene Oral RfD." Draft report excerpt submitted to U.S. EPA Naphthalene RfD Work Group. August 30.

Beck, B.D. 1987. "Acute and Chronic Toxicity of Trichloroethylene," "Non-Carcinogenic Risk Assessment," "The Role of Peroxisomal Proliferation in Trichloroethylene Hepatotoxicity and Carcinogenicity." Draft NESCAUM (Northeast States for Coordinated Air Use Management) Health Assessment Document.

Beck, B.D. 1982. The Use of Bioassays to Assess the Toxicity of Particulates; Evaluation of Bioassays. In *Appendix 2: Toxic Effects of Airborne Particulates*, pp 119 - 167, Appendix to Report "Analysis of Health Effects Resulting from Population Exposures to Ambient Particulate Matter" Prepared by Harvard University, Energy and Environmental Policy Center, for U.S. Dept. of Energy, Agreement No. DE-AC02-81EV10731.

Beck, B.D. 1975. *Activity of Three Murein Hydrolases During the Cell Cycle of Escherichia coli. K-12.* Ph.D. dissertation, Tufts University, Medford, MA.

INVITED LECTURES/OTHER PRESENTATIONS

1985 - present:

3/97 - "Principles of Toxicology." Harvard Center for Risk Analysis Course on "Analyzing Risk: Assessment and Management." Boston, MA.
12/96 - "Risk Assessment for Criteria Pollutants *versus* Other Noncarcinogens: The Difference Between Implicit and Explicit Conservativism." Rutgers University 2nd Annual Workshop on "The Evaluation of EPA 10X Safety Factors in Health Risk Assessment." Nutley, NJ.
9/96 - "The Quantitative Use of Information on Susceptibility in Risk Assessment: Where is it working or not working? How Can We Make It Better?" Third Annual NHEERL Symposium on Susceptibility and Risk Assessment. Raleigh, NC.
9/96 - "Principles of Toxicology." Harvard Center for Risk Analysis Course on "Analyzing Risk: Assessment and Management." Boston, MA.
8/96 - "The Role of Risk Assessments in Superfund." American Bar Association, Orlando, FL.
12/95 - "Use of Monte Carlo Arsenic (As) Model to Predict Distributions of Urine Arsenic at a Mining and Milling Site." Society for Risk Analysis, Honolulu, HI.
10/95 - "Use of Information on Variations in Susceptibility - Ozone." ILSI Risk Science Institute Workshop on Human Variability, Washington, DC.
10/95 - "Evaluation of Health Effects Resulting from Accidental Exposures." Michigan Society for Risk Analysis, Dearborn, MI.
9/95 - "Principles of Toxicology." Harvard Center for Risk Analysis Course on "Analyzing Risk: Assessment and Management", Boston, MA.
6/95 - "Validation of an Arsenic Exposure Model at a Mining and Milling Site through Urinalysis." "Use of an Arsenic Exposure Model at a Gold Mining and Milling Site." Second International Conference on Arsenic Exposure and Health Effects, San Diego, CA.
7/94 - "A Review of Scientific Issues Pertaining to Arsenic." Society for Environmental Geochemistry and Health Conference on Lead and Arsenic Exposure in the Rocky Mountains, Salt Lake City, UT.
5/94 - "Use of Lead Exposure Assessment in the Regulatory Process." International Lead Zinc Research Organization Lead Exposure Assessment Workshop, Research Triangle Park, NC.
3/94 - "Non-linearities in Arsenic Risk Assessment." Boston Risk Assessment Group, Cambridge, MA.
3/93 - "Basic Risk Assessment: Current Developments": Continuing Education Course, Society of Toxicology, New Orleans, LA.
3/92 "A Review of the Bioavailability of Petroleum Constituents." West Coast Soils and Groundwater Conference, Long Beach, CA.
3/92 "Bioavailability of Metals and Organics." Workshop on Human Health and Ecological Risk Assessments for Contaminated Sites, Toronto, Canada.
2/92 "Improvements in Quantitative Noncancer Risk Assessment." Chair of Symposium of Society of Toxicology Meeting, Seattle, WA.
2/92 "Perspectives on the Development of Soil Cleanup Levels at Mining Sites." Colorado Bar Association. Denver, CO.
11/91 "Environmental Law Update: Toxic Torts and How Clean is Clean?" Squire, Sanders & Dempsey, Cincinnati, OH.
10/91 "Risk Assessment for Indoor Air: Evaluating Risks to Susceptible Populations." NATO/CCMS-COST 613 Joint Workshop, Kloster Banz, Bavaria, Germany.
2/91 "An Update on Exposure and Risks of Lead." Chair of Symposium at Society of Toxicology Meeting.

2/90 "Inhalation Risk Assessment." Chair of Symposium at Society of Toxicology meeting.
1/90 "The Use of Structure Activity Relationships for Alkyl Phenol Risk Assessment" New England Society for Risk Analysis, Boston, MA; RJR/Nabisco, Winston-Salem, NC.
1/90 "The Use of Structure Activity Relationships in Risk Assessment" Harvard School of Public Health, Boston, MA; Northeastern University, Boston, MA.
11/89 "How Protection Levels are Developed and What They Mean," Course on Risk Assessment and Epidemiology for Lawyers, Harvard School of Public Health, Boston, MA.
9/89 "An Environmental Health Case Study," Tufts Medical School, Boston, MA.
3/89 "Impact of Lead Derived from Mining Sources on Blood Lead," Boston Risk Assessment Group, Boston, MA.
2/89 "Ecological and Health Risk assessment for Arsenic in Soil," Society of Toxicology, Atlanta, GA.
12/88, 1/89, 9/89, 10/89 and 4/90 "Risk Assessment for Hazardous Waste Sites, Including a Perspective on Toxic Torts." Executive Enterprises, Inc., Washington, DC, Chicago, IL, Philadelphia, PA, and Orlando, FL.
10/88 "Ozone Toxicology and Risk Assessment," Harvard School of Public Health, Boston, MA.
10/88 "Risk Assessment for Arsenic in Soil," University of Massachusetts, Amherst, MA.
9/88 "The Use of Animal Bioassays to Assess Lung Toxicity," NESCAUM, Princeton, NJ.
6/88 "Review of Epidemiological and Toxicological Studies on Mining Derived Lead," EPA, Philadelphia, PA.
3/88 "Assessment of Impact on Blood Lead of Lead from Mining Sources," EPA, Washington, DC.
2/88 "Regulatory Toxicology," Tufts University School of Medicine, Boston, MA.
12/87 "Risk Assessment for Soil," Harvard School of Public Health, Boston, MA.
12/87 "Health Effects of Ozone and the Clean Air Act," New England Chapter for Society for Risk Analysis, Cambridge, MA.
11/87 "Health Effects of Ozone," Harvard School of Public Health, Boston, MA.
9/87 "Health Risk Assessment for Soil," University of Massachusetts, Amherst, MA.
4/87 "Key Issues in Addressing Adverse Effects of Ozone," University of Massachusetts, Amherst, MA.
1/87 "Risk Assessment for Dioxin in Soil," MIT, Cambridge, MA.
10/86 "Pulmonary Toxicology," Harvard School of Public Health, Boston, MA.
10/86 "Risk Assessment," University of Massachusetts, Amherst, MA.
10/86 "Regulatory Toxicology," Tufts University School of Medicine, Boston, MA.
7/86 "Health Effects of Indoor Air Pollutants," Region I, EPA, Lexington, MA.
6/86 "Health Effects of Radon," Society of Women Engineers, Hartford, CT.
6/86 "Contacting the Health and the Medical Community About the Adverse Effects of Ozone," EPA, Washington, DC.
6/86 "Animal Toxicology," Region I EPA, Boston, MA.
4/86 "Health Effects of Ozone," NESCAUM meeting, Newport, RI.
2/86 "Pulmonary Toxicology," Region I EPA, Boston, MA.
12/85 "Toxicology of Dioxin," EPA Dioxin workshop, Lexington, MA.
11/85 "Animal Bioassays," Harvard School of Public Health, Boston, MA.
11/85 "Pulmonary Toxicology," Harvard School of Public Health, Boston, MA.
10/85 "Indoor Air Pollution," Air Pollution Control Association meeting, Enfield, CT.
1/85 "Indoor Air Pollution," NESCAUM workshop, Northampton, MA.

EDITOR

1991. *Trace Substances in Environmental Health : Supplement to Volume 14 (1992) of Environmental Geochemistry and Health. Proceedings of the 25th Annual Conference on Trace Substances in Environmental Health*, May 20-23, Columbia, MO.

1995 to present. *Human and Experimental Toxicology* (Editorial Board)

REVIEWER

Fundamental and Applied Toxicology; Cancer Research; Environmental Research; Annals of Internal Medicine; Human and Ecological Risk Assessment; Journal of Society of Environmental Geochemistry and Health; Human and Experimental Toxicology.

CONTINUING EDUCATION COURSES

- Pulmonary Pathophysiology, University of Vermont Medical School, 1979.
- Mid-America Course in Toxicology, 1988.
- Respiratory Tract Toxicology by Classes of Agents, Society of Toxicology, 1988.
- Neurotoxicology, Society of Toxicology, 1989.
- Toxicity of Agents: Pesticides, Society of Toxicology, 1990.
- Target Organ Toxicity: Advanced Hepatotoxicity, Society of Toxicology, 1990.
- Environmental Toxicology, Society of Toxicology, 1991.
- Case Studies in Risk Assessment: Emphasis on Exposure, Society of Toxicology, 1992.
- International Harmonization: Update on Scientific and Regulatory Issues. Part II: Toxic Substances and Environmental Issues, Society of Toxicology, 1994.
- Epidemiology for Toxicologists, Society of Toxicology, 1996.
- Principles of Metal Toxicology, Society of Toxicology, 1997.
- Benchmark Dose, Society of Toxicology, 1997.

Analysis of Exposure-Response Assessment Used in Support of the Environmental Protection Agency's Proposed Ozone Standards

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Executive Summary

This report assesses the validity and appropriateness of key health studies and the risk assessment comprising the scientific basis for the U.S. Environmental Protection Agency's (EPA's) proposed change to the National Ambient Air Quality Standard (NAAQS) for ozone. The current ozone standard is 0.12 ppm, 1-hour average, one exceedance per year (meaning that the standard cannot be exceeded on average more than 1 day per year). This standard is based on concern for acute respiratory effects reported in many controlled human exposure studies and animal studies. EPA proposes to lower the standard to a level in the range of 0.07 - 0.09 ppm ozone, 8-hour average, 1-5 exceedances per year based on concern for acute health effects at low ozone exposures.

The major health concern resulting from ozone exposure is effects to the respiratory system, primarily a decrease in the forced expiratory volume in one second (FEV_1) and subjective symptoms of cough and pain on deep inspiration. The health effects resulting from ozone exposure are seen most readily in exercising adults. The majority of controlled human studies have been concerned with the effects of various ozone concentrations in healthy subjects performing either continuous exercise or intermittent exercise. Controlled human exposure studies of this type have provided the strongest and most quantifiable concentration-response data on the health effects of ozone. As a result of these studies, a large body of data regarding the interaction of ozone concentration, breathing, and duration of exposure is available. As reported by EPA in their Criteria Document (1993), the most salient observations from these studies are (1) ozone concentration is more important than either breathing or exposure duration in determining pulmonary responses; and (2) normal healthy subjects exposed to ozone concentrations $\leq$ 0.12 ppm (the level of the current NAAQS) develop significant reversible, transient decrements in pulmonary function if breathing intensity and/or duration of exposure are increased sufficiently (*i.e.*, during exercise). There is typically a large intersubject variability in physiologic and symptomatic responses to ozone; with most individuals these responses are reproducible. EPA judged three health endpoints, all associated with moderate exercise, to be adverse: FEV_1 decrements of equal to or more than 15% for 8-hour exposures, FEV 1 decrements of equal to or more than 20% for 8-hour exposures, and moderate-to-severe pain on deep inspiration for 1-hour exposures.

Ozone was first regulated by EPA in 1971 under a NAAQS primary standard. The process for revising a NAAQS standard requires preparation of a "criteria document," which summarizes all relevant scientific knowledge. EPA initiated action to update their air quality criteria document for ozone in 1992. The most recent version of that document reviewed for this report was issued in December 1993. EPA drafted a Staff Paper (August 1995), based on the scientific evidence presented in the Criteria Document. In addition, EPA conducted and presented estimates based on a quantitative analysis of human health risk due to ozone exposure for nine alternative standards. The analysis consists of two major components: exposure-response modeling of health effects from ozone exposure, and a model that quantifies human exposure to ozone. Exposure-response modeling was conducted separately for two types of studies: chamber studies and hospital admission studies. For hospital admission studies, Whitfield *et al.* (1995) modeled the exposure-response relationship of the hospital admissions for asthmatics in New York City during the summer of 1988 based on a study conducted by Thurston *et al.* (1992). Whitfield *et al.* (1995) also modeled the exposure-response for nine health effects as characterized in seven chamber studies

EPA used a separate model - the probability NAAQS exposure model for ozone (pNEM/O_3) - to evaluate human exposure to ozone. The pNEM/O_3 model, which is run on a mainframe computer, takes into account many variables. Although the variables affecting ozone exposure are numerous, they generally fall into two categories: those affecting ozone level and those affecting activity level of the persons exposed. Ozone level, in turn, is impacted by numerous variables such as geographic location, season, temperature, and ventilation/air conditioning parameters. Since ozone concentrations also vary during the day, a complex model was developed (primarily by Ted Johnson) to take into account all of these variables, many of which affect one another.

EPA combined the results of the exposure-response model and the exposure model by calculating headcount risks. Headcount risks estimate the number of people that would be adversely affected in a particular population (*e.g.*, children) given normal movement and activity patterns and given that a particular NAAQS is just attained in a particular city (p.103, 115 Staff Paper). Risk estimates were calculated for each acute health effect separately. For each city, the number of people potentially affected were estimated for each regimen (*e.g.*,

8-hour, moderate exertion, children, FEV_1 decrement of greater than or equal to 15%), for each air quality scenario.

EPA's overall approach to assessing exposure to ozone and the exposure-response relationship for ozone is commendable. The chamber studies were generally well conducted by qualified scientists and their use as the basis of the exposure-response modeling is appropriate. However, EPA appears to have selected the studies with the largest response rates at the lowest concentrations, which will result in an overestimate of risk. In addition, using data based on adults to establish exposure-response relationships for children and adolescents is reasonable for FEV_1 decrements but overly conservative for symptoms such as PDI, because children and adolescents do not seem to experience such symptoms.

Additional concerns or limitations include not applying consistent criteria when choosing the chamber studies, possible contamination of the chambers with volatile organic compounds, and the issue of reduced response to ozone in adapted subpopulations. We recommend that the issue of chamber contamination be resolved and that more representative chamber studies be used to develop the exposure-response relationship. In addition, we believe that EPA should consider two separate dose-response functions: one based on the chamber studies in which an exercise regimen was used; and another based on chamber studies in which the participants activity pattern (*e.g.*, duration) is similar to the activity levels recorded in the diary studies

The $pNEM/O_3$ exposure model is comprehensive and its overall conceptual framework is sound. It allows for interaction between the variables (*e.g.*, temperature and ozone concentration) in addition to taking into account numerous variables (*e.g.*, EVR, activity patterns, location). However, it appears to overestimate exposures and these overestimates should be addressed. We recommend that EVR be corrected based on new field studies, and that $pNEM/O_3$ be corrected for EVR overestimates as well as other overestimates.

We considered nine health endpoints evaluated by Whitfield *et al.* (1995). In virtually all of these cases, the exposure-response relationship illustrated in Whitfield *et al.* (1995) reaches a population response rate of zero

at 0.08 ppm at 8-hour exposures. The population response rate at 0.08 ppm for the two other cases is close to zero. In view of these results, we conclude that the Staff has not justified the regulation of ozone concentrations as low as 0.07 ppm. For most of the health endpoints considered in the Staff Paper as important, the exposure-response relationships published in Whitfield *et al.* (1995) indicate population response rates of zero at ozone concentrations of 0.22 ppm to 0.08 ppm. Therefore, the data suggest that a threshold exists below which there is no effect.

Once the exposure issues and the exposure-response relationship are resolved, the selection of a specific level and number of allowable exceedances is a policy judgment. Although it was the consensus of the CASAC Panel that the ranges of concentrations and allowable exceedances by the Agency were appropriate, a number of Panel members expressed "personal" preferences for the level and number of allowable exceedances (Wolff, 1995). Of the ten panel members who expressed their opinions, all ten favored multiple allowable exceedances, three favored a level of 0.08 ppm, one favored the mid to upper range (0.08 - 0.09 ppm), three favored the upper level (0.09 ppm), one favored 0.09-0.10 ppm range with advisories issued when the 8-hour ozone concentration was forecasted to exceed 0.07 ppm, and two simply endorsed the range presented by the Agency as appropriate and stated that the selection should be a policy decision.

Recommendations

Additionally,

EPA should choose more representative chamber studies, including those that show adaptation effects, and repeat the analysis using all the chamber studies which meet the selection criteria.

EPA should alter the pNEM/O_3 model to better estimate EVR, using new field estimates.

EPA should revise the pNEM/O_3 model to more accurately estimate “true” ozone concentrations or revise headcount risks to reflect the overestimate provided by pNEM/O_3.

EPA should revise the methodology used in the pNEM/O_3 model to rollback ozone concentrations or revise headcount risks to reflect overestimates made by the pNEM/O_3.

EPA should evaluate the impact on health endpoints of short-term adaptation.

EPA should conduct a sensitivity analysis for Los Angeles comparing response rate when adaptation is and is not taken into account.

EPA should resolve the issue of chamber contamination.

We recommend that the regulatory concentration of ozone be chosen from the upper end of the range of ozone concentrations (0.09 ppm for 8 hours or 0.12 for 1 hour ppm) for several reasons. The headcount risks at all concentrations are likely overestimates due overestimates of EVR (not correcting for arm movement and increases in temperature *etc.)* and an overestimate of the number of exercisers at higher ozone concentrations; actual ozone concentrations; and the exposure-response relationship due to chamber contamination, EPA's choice of studies (EPA tended to choose the studies with the highest responses), and EPA's decision not to adjust for adaptation in cities where this would be expected to occur. Thus the benefits of attaining the proposed standards are overstated. Moreover, the uncertainty in the modeling procedure is such that it is difficult to distinguish between some of the proposed standards.

6 Conclusions and Recommendations

In this section we provide detailed conclusions (Section 6.1) and a summary with recommendations (Section 6.2).

6.1 Conclusions

Exposure-Response Analysis

EPA's use of outdoor children as the most exposed population is reasonable.

Using exposure-response data representing adult responses to ozone in chamber studies to estimate the exposure-response of children is uncertain. However, based on the limited data available and EPA's analysis, we believe that this approach is reasonable for lung function decrements, but results in overestimates for symptoms such as PDI.

Adaptation lowers short-term lung function response rates to ozone. EPA's analysis is based on short-term, acute effects, since as stated by EPA, chronic effects have not been established. Therefore, the risks for major populations (*e.g.*, Los Angeles) exposed to concentrations of ozone associated with adaptation are likely overestimated.

No exposure-response data exist for concentrations under 0.08 ppm. Extrapolation below 0.08 ppm is highly uncertain (even more uncertain than portrayed by EPA).

Most health endpoints have population response rates of zero at 0.08 ppm. For health endpoints for which the population response exceeds zero at ozone concentrations below 0.08 ppm, the response rates are very low and often the 90% confidence interval includes 0 at ozone concentrations below 0.08 ppm.

EPA's analysis of the hospital admission studies does not justify making the ozone standard more stringent.

Exposure Analysis

The EVR distributions used in the pNEM/O_3 model are based on problematic data. The major shortcomings result in overestimates of VR. Calibrations are done primarily with leg exercise, whereas most recreational exercise and occupational endeavors involve both arm and

leg exercise. This results in an overestimation of VR by about 5-8% for the lower ranges of HR (Adams *et al.*, 1995). The data used to develop the VR *vs.* HR relationship do not adequately account for factors that increase HR without a corresponding increase in VR (*e.g.*, heat stress, anxiety, excitement), resulting in a likely overestimate of VR.

The pNEM/O_3 model is probably a valid technique when used for population exposure estimates to current ozone concentrations, but suffers from a serious drawback when used to assess future ozone scenarios. The methodology used in the pNEM/O_3 model to estimate ozone concentrations under various regulation scenarios is approximate, with an apparently net positive bias. An attempt at validating the ozone adjustment procedure in the pNEM/O_3 technique (Johnson, 1995) showed a significant bias in the ozone adjustment procedure, resulting in approximately 50% higher ozone concentrations at the 50th percentile of the estimated hourly ozone concentrations.

An additional study conducted by Johnson *et al.* (1996) indicated that the pNEM/O_3 model overestimates exposures by a factor of up to 1.7 when the estimates are compared to monitoring data.

Proposed Standards

EPA's results show that attaining a 1-hour standard reduces the risk of experiencing health effects associated with either 1-hour or 8-hour ozone exposures. Likewise, attaining any of the alternative 8-hour standards reduces the risk of experiencing health effects associated with either 8-hour or 1-hour ozone exposures. Based on these analyses, EPA believes that adequate reductions in risks from both 1-hour and 8-hour effects can be achieved through a primary standard with an averaging time of either 1 or 8 hours.

Based on the risk analyses for lung function decrements, respiratory symptoms, and excess hospital admissions, there appears to be only a small to modest difference in the median risk estimates between just attaining a 1 expected and 5 expected exceedance 8-hour standard when the level is set at 0.08 or 0.09 ppm.

For most of the nine health endpoints considered in the Staff Paper to be important, the exposure-response relationships published in Whitfield *et al.* (1995) indicate population response rates of zero at ozone concentrations below 0.08 ppm. Hence, reducing the maximum allowed concentration from 0.08 to 0.07 ppm has no effect on the headcount risk for these endpoints. Thus EPA has not justified a 0.07 ppm standard.

We recognize that an 8-hour averaging time may be better than a 1-hour average time based on biological responsiveness. However, based on the headcount risks, one can get almost the same risks regardless of whether an 8-hour or 1-hour averaging time is used depending on the ozone concentration chosen. For example, as shown in Table 5-1 the risks (with one expected exceedance) are virtually identical for 0.12 ppm ozone with a 1-hour averaging time and 0.09 ppm ozone with an 8-hour averaging time.

Since the standard with 5 expected exceedances is more robust and will result in fewer areas going in and out of attainment (flip-flopping), we believe that the 5-expected exceedance is a better choice.

The health endpoints included moderate-to-severe symptoms experienced during heavy exertion in response to an acute ozone exposure and moderate-to-severe symptoms experienced during moderate exertion in response to extended ozone exposure. In virtually all of these cases, the exposure-response relationship illustrated in Whitfield reaches a population response rate of zero. The population response rate at 0.07 ppm for the two other cases is close to zero. In view of these results, we conclude that the Staff Paper has not justified the potential regulation of ozone to concentrations as low as 0.07 ppm based on symptoms.

The hospital studies are too uncertain to use as a basis for making the ozone standard more stringent.

6.2 Summary and Recommendations

EPA's overall approach to assessing exposure to ozone and the exposure-response relationship for ozone is commendable. The chamber studies were generally well conducted by qualified scientists and their use as the basis of the exposure-response modeling is appropriate. However, EPA appears to have selected the studies with the largest response rates at the lowest concentrations, which will result in an overestimate of risk. In addition, using data based on adults to establish exposure-response relationships for children and adolescents is reasonable for FEV_1 decrements but overly conservative for symptoms such as PDI, because children and adolescents do not seem to experience such symptoms.

Additional concerns or limitations include not applying consistent criteria when choosing the chamber studies, possible contamination of the chambers with volatile organic compounds, and the issue of reduced

response to ozone in adapted subpopulations. We recommend that the issue of chamber contamination be resolved and that more representative chamber studies be used to develop the exposure-response relationship. In addition, we believe that EPA should consider two separate dose-response functions: one based on the chamber studies in which an exercise regimen was used; and another based on chamber studies in which the participants activity pattern (*e.g.*, duration) is similar to the activity levels recorded in the diary studies.

The pNEM/O_3 exposure model is comprehensive and its overall conceptual framework is sound. It allows for interaction between the variables (*e.g.*, temperature and ozone concentration) in addition to taking into account numerous variables (*e.g.*, EVR, activity patterns, location). However, it appears to overestimate exposures and these overestimates should be addressed. We recommend that EVR be corrected based on new field studies, and that pNEM/O_3 be corrected for EVR overestimates as well as other overestimates (*e.g.*, rollback of ozone concentrations).

We considered nine health endpoints evaluated by Whitfield *et al.* (1995). In virtually all of these cases, the exposure-response relationship illustrated in Whitfield *et al.* (1995) reaches a population response rate of zero at 0.08 ppm at 8-hour exposures. The population response rate at 0.08 ppm for the two other cases is close to zero. In view of these results, we conclude that the Staff has not justified the regulation of ozone concentrations as low as 0.07 ppm. For most of the health endpoints considered in the Staff Paper as important, the exposure-response relationships published in Whitfield *et al.* (1995) indicate population response rates of zero at ozone concentrations of 0.22 ppm to 0.08 ppm.

Once the exposure issues and the exposure-response relationship are resolved, the selection of a specific level and number of allowable exceedances is a policy judgment. Although it was the consensus of the CASAC Panel that the ranges of concentrations and allowable exceedances by the Agency were appropriate, a number of Panel members expressed "personal" preferences for the level and number of allowable exceedances (Wolff, 1995). Of the ten panel members who expressed their opinions, all ten favored multiple allowable exceedances, three favored a level of 0.08 ppm, one favored the mid to upper range (0.08 - 0.09 ppm), three favored the upper

level (0.09 ppm), one favored 0.09-0.10 ppm range with advisories issued when the 8-hour ozone concentration was forecasted to exceed 0.07 ppm, and two simply endorsed the range presented by the Agency as appropriate and stated that the selection should be a policy decision.

Recommendations

EPA should choose more representative chamber studies, including those that show adaptation effects, and repeat the analysis using all the chamber studies which meet the selection criteria.

EPA should alter the pNEM/O_3 model to better estimate EVR, using new field estimates.

EPA should revise the pNEM/O_3 model to more accurately estimate "true" ozone concentrations or revise headcount risks to reflect the overestimate provided by pNEM/O_3.

EPA should revise the methodology used in the pNEM/O_3 model to rollback ozone concentrations or revise headcount risks to reflect overestimates made by the pNEM/O_3.

EPA should evaluate the impact on health endpoints of short-term adaptation.

EPA should conduct a sensitivity analysis for Los Angeles comparing response rate when adaptation is and is not taken into account.

EPA should resolve the issue of chamber contamination.

We recommend that the regulatory concentration of ozone be chosen from the upper end of the range of ozone concentrations (0.09 ppm for 8 hours or 0.12 for 1 hour ppm) for several reasons. The headcount risks at all concentrations are likely overestimates due overestimates of EVR (not correcting for arm movement and increases in temperature *etc.)* and an overestimate of the number of exercisers at higher ozone concentrations; actual ozone concentrations; and the exposure-response relationship due to chamber contamination, EPA's choice of studies (EPA tended to choose the studies with the highest responses), and EPA's decision not to adjust for adaptation in cities where this would be expected to occur. Thus the benefits of attaining the proposed standards are overstated. Moreover, the uncertainty in the modeling procedure is such that it is difficult to distinguish between some of the proposed standards.